

## Aerosonde Technical Development

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### LONG-TERM GOALS

The Aerosonde development program has been in effect since the early 1990's with the first field trial flown at the end of 1995 as part of the Maritime Continental Thunderstorm Experiment of northern Australia. Since that time, the Aerosonde has been deployed in diverse jurisdictions and climates in collaboration with the weather services of Australia, Canada, Taiwan and the U.S. Principal results are as follows:

- more than 1000 flight hours since 1995
- seven flights longer than 24 hrs with the longest flight of 30.5hr.
- flights in severe tropical thunderstorms ( Western Australia, South China Sea)
- flights in midlatitude icing (Vancouver Island) and arctic environment (Barrow)
- fully automatic flight from takeoff to landing
- control of multiple aircraft from a single ground station
- enroute control-by-telephone from weather forecasting centers
- first unmanned Atlantic crossing; 3270 km from Newfoundland to Scotland on 20-21 August, 1998 in 26 hr 45 min using 4 kg of fuel

In 1999, ONR funded further development of the Aerosonde at the University of Washington. The major goals are to develop the necessary tools for a technology base supporting Aerosonde class aircraft design while improving the current vehicle. Secondary goals for the UW are to integrate the

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Aerosonde development effort into the educational mission of the Department of Aeronautics and Astronautics.

## **OBJECTIVES**

The work at the UW to achieve these goals is divided into six major task areas. The tasks will be broken down into specific objectives:

1. Investigation of the aerodynamic characteristics of the current Aerosonde configuration with the goal of improving the drag characteristics,
  - 1.1. Test modifications to the existing airframe in the Kirsten wind tunnel to measure drag reduction of candidate configurations.
  - 1.2. Use CFD methods, supported by wind tunnel validation, to simulate and understand aerodynamic behavior of Aerosonde-class designs.
  - 1.3. Develop rapid wind tunnel model construction techniques for reduced cost and short response times.
2. Development of a simulation to enable rapid evaluation of autopilot designs,
  - 2.1. Develop real-time simulation code for the Aerosonde using SIMULINK.
  - 2.2. Implement the Aerosonde flight control system using SIMULINK, REAL-TIME WORKSHOP and STATEFLOW to speed up revision of current flight control systems.
3. Analysis of the structural/aeroelastic characteristics of the current airframe to evaluate the influence of structural/aeroelastic deformations on the vehicle performance.
  - 3.1. Develop computational and experimental tools for the rapid structural/aeroelastic analysis, design, and construction of low-cost UAV airframes.
  - 3.2. Build technology to support structural/aeroelastic simulation and modification of Generation-I Aerosondes as well as future generation Aerosondes.
4. Development of trajectory optimization/planning algorithms for operations.
  - 4.1. Develop a real-time trajectory and flight path planning algorithm for the Aerosonde that determines the optimal path under various types of constraints.
5. Involve graduate students in graduate research
  - 5.1. In the application and development of simulation tools
  - 5.2. In design of modifications to Generation I Aerosondes and future designs
6. Incorporate design and analysis of Aerosonde class vehicles in the undergraduate curriculum.
  - 6.1. Undergraduates will design and test UAVs as part of the capstone design course.
  - 6.2. Students will participate in the design and building of UAV hardware
  - 6.3. Independent studies projects will explore new designs.

## **APPROACH**

The discussion in the following section will follow the specific tasks outlined above.

- 1.1. Test modifications to the existing airframe in the Kirsten wind tunnel. (Eberhardt)
  - 1.2. Apply three levels of aerodynamic prediction tools to Aerosonde configurations: vortex lattice, panel methods and Navier-Stokes simulations and run extensive wind tunnel tests. (Eberhardt, Livne)
  - 1.4. Use CAD modeling (Unigraphics) in student design projects to reduce model costs. Rapid prototyping will allow multiple designs to be tested to optimize the next generation of Aerosonde-class UAV's. (Livne)
- 2.1. Review existing real-time simulation code of the Aerosonde and identify components related to the vehicle configuration, aerodynamics, propulsion and control. (Ly)
  - 2.2. Divide the current Aerosonde flight control system into longitudinal and lateral control laws. These control laws and their functionality will then be re-coded into a convenient rapid prototyping platform. (Ly)
- 3.1. Develop quick material behavior characterization capability integrated with rapid geometry finite-element structural modeling for all composite UAV airframes. Use existing Aerosondes and candidate configuration future UAVs for validation through static and modal tests. (Livne)
  - 3.2. Develop structural/aeroelastic analysis and optimization capability (supported by modal tests and wind tunnel tests) with emphasis on possible non-linearities and uncertainties due to low cost manufacturing. (Livne)
- 4.1. Review various numerical schemes for solving the trajectory optimization problem. (Ly, Vagners)
- 5.1. Train graduate research assistants in the use of simulation and experimental tools and have them interact with the industry developers. (All)
  - 5.2. Include graduate students as teaching assistants and team leaders for the design of new Aerosonde-class UAV's. (All)
- 6.1. Focus the two-quarter airplane design sequence (AA410/411) on the design, testing and building of UAV's of the Aerosonde-class. (Livne)
  - 6.2. Students will participate in the building of hardware through the airplane design courses, independent studies and extra-curricular activities. (All)
  - 6.3. Independent projects for credit will be offered so students can focus on a particular technology in the program that interests them. (All)

## **WORK COMPLETED**

Once again, the work completed will be broken up by tasks.

- 1.1. Three separate drag reduction studies have been performed in the Kirsten wind tunnel. The most recent was to explore dropping the wing incidence by lowering the wing mounting deeper into the fuselage. Also tested were several propellers.
- 1.2. Students have used vortex lattice methods and DATCOM to design a UAV for the student design project. Surface models for several UAVs, including the existing Aerosonde, have been

created as input to CMARC. The existing Aerosonde and a student design project from the design courses have been tested in the wind tunnel.

- 1.3. The senior design class has worked with ATS to develop a process for rapid prototyping. A wind tunnel model was built by ATS and an airframe was built by students using composite materials. A joined-wing UAV was built using conventional composite foam/balsa construction.
- 2.1. A set of C-codes have been extracted from the existing real-time simulation code of the Aerosonde. SIMULINK files have been developed that produce the same forces and moments as provided in the existing aerodynamics and engine propulsion modules.
- 2.2. Work is completed in the redesign of the lateral control law gains to reduce roll oscillations and coupled pitch instabilities found in recent flight operations.
- 3.1. The US Air Force structural/aeroelastic optimization code, ASTROS, was used to model the student design project and optimize its structure. A prototype vehicle has been built using inexpensive materials and construction techniques.
- 4.1. Work on trajectory optimization has not started.
- 5.1. Graduate students were involved in wind tunnel testing of the Aerosonde this summer to look at wing incidence and propeller efficiency. Graduate students have been trained to use CMARC, SIMULINK, SANDY, REALTIME WORKSHOP and STATEFLOW, and are using these codes for simulations.
- 5.2. A TA (Teaching Assistant) helped with the AA410/411 design course last year.
- 6.1. Two wind tunnel tests for existing Aerosondes were performed by the AA410/411 design class last year. These tests led to better understanding of Aerosonde aerodynamic limitations. Students studied the stall patterns on the wing and ailerons and measured stability derivatives.
- 6.2. Students in AA410/411 designed a new UAV, called the Local Hawk, and tested it in the wind tunnel this year. Currently 13 students are working on three UAV's as part of an extra-curricular activity.
- 6.3. A joined wing UAV was designed and built by students. A student will receive independent study credit by acting as lead test engineer for an upcoming wind tunnel test.

## RESULTS

Most tasks are still in progress and progress has been written in the previous section. This section will focus on only those results which can result in significant impact in this or related programs.

- 1.1. Reducing the incident angle of the wing on the current Aerosonde reduces drag by 5%. Interference from the static pressure probe impacts total pressure measurements, which has caused problems in the Aerosonde control system.
- 1.3. A wind tunnel model was built demonstrating a rapid prototyping capability.
- 2.1. Interfaces with the existing C-codes have been successfully developed enabling steps to the full development of the SIMULINK codes.

- 2.2. A flight control system has been implemented and tested on a UAV.
- 3.1. The feasibility of designing and building low-cost UAVs in a short time has been demonstrated. ASTROS finite element modeling based on coupon tests of graphite/epoxy and kevlar/epoxy layouts guided design and construction of the Local Hawk.
- 5.1. Three graduate students are currently working on the Aerosonde program.
- 5.2. Graduate students are leading design and building efforts with undergraduates.
- 6.1. UAV's of the Aerosonde-class have been integrated into the curriculum of the capstone design courses (AA410/411).
- 6.2. 10 undergraduate students are working on the program as an extra-curricular activity. Students have designed and built a joined-wing design.

## **IMPACT/APPLICATIONS**

- 1. Aerodynamic improvements will help increase range and endurance of the existing Aerosonde, allowing it to collect meteorological data over a larger area.
- 2. Low cost, fast construction of prototypes can lead to quicker and cheaper engineering solutions.
- 3. Redesign of the lateral control laws provides improved lateral stability for the current Aerosonde. Flight tests confirm the results predicted in design.

## **TRANSITIONS**

- 1. Placement of pressure probes has been changed as a result of wind tunnel experiments.
- 2. Real-time codes were successfully developed for the flight control laws of the Raven (human-powered) vehicle. This vehicle was used as a testbed since its control system is simpler and uses similar hardware as the Aerosonde which includes a Tattletale Model 8 processor, 8 analog channels and one digital channel and two servo outputs.

## **RELATED PROJECTS**

"Aerosonde Performance Improvement and Economical Wide-Scale Weather Reconnaissance over the Oceans," PI: D. S. Eberhardt, Co-PI: E. Livne, U-L Ly, and J. Vagners. ONR DURIP (Equipment Grant). Grant N00014-98-1-0372. The funding provides the equipment required to carry out the research. Ten Aerosondes have been purchased and used for collecting data pertinent to this research project. In addition, the Aerosondes have been used for trial weather collection programs.

## **PUBLICATIONS**

"Aerosonde Operations in 1998". Vagners, J. (with T. McGeer, G. Holland, G. Tyrrell, J. Becker, P. Ford), Proc. Third Symposium on Integrated Observing Systems: 60-63. American Meteorological Society, Dallas, January 1999

"The Evolution of the Senior Airplane Design Course at the University of Washington", Livne, E., AIAA Paper 99-0570, AIAA Aerospace Sciences Meeting, Reno, Nevada, January 1999.

"Historic Crossing: An Unmanned Aircraft's Atlantic Flight", Vagners, J.(with T. McGeer), GPS World 10 (2), Feb 1999

"The Aerosonde: Opportunities for Miniature Robotic Aircraft Following the 1998 Atlantic Crossing", Vagners, J. (with T. McGeer, G. Holland), Fourth Annual Airborne Remote Sensing Conference and Exhibition/21st Canadian Symposium on Remote Sensing, Ottawa, Ontario, Canada, 21-24 June 1999

"Quantitative Risk Management as a Regulatory Approach to Civil UAV's", Vagners, J. (with T. McGeer, L. Newcombe), Second Annual European Unmanned Vehicle Systems Association Conference on UAV Certification, Paris, France, June 9, 1999

"Wide-scale Use of Long Range Miniature Aerosondes Over the World's Oceans", Vagners, J. (with T. McGeer), Proceedings of the AUVSI 26th Annual Symposium, Baltimore, July, 1999